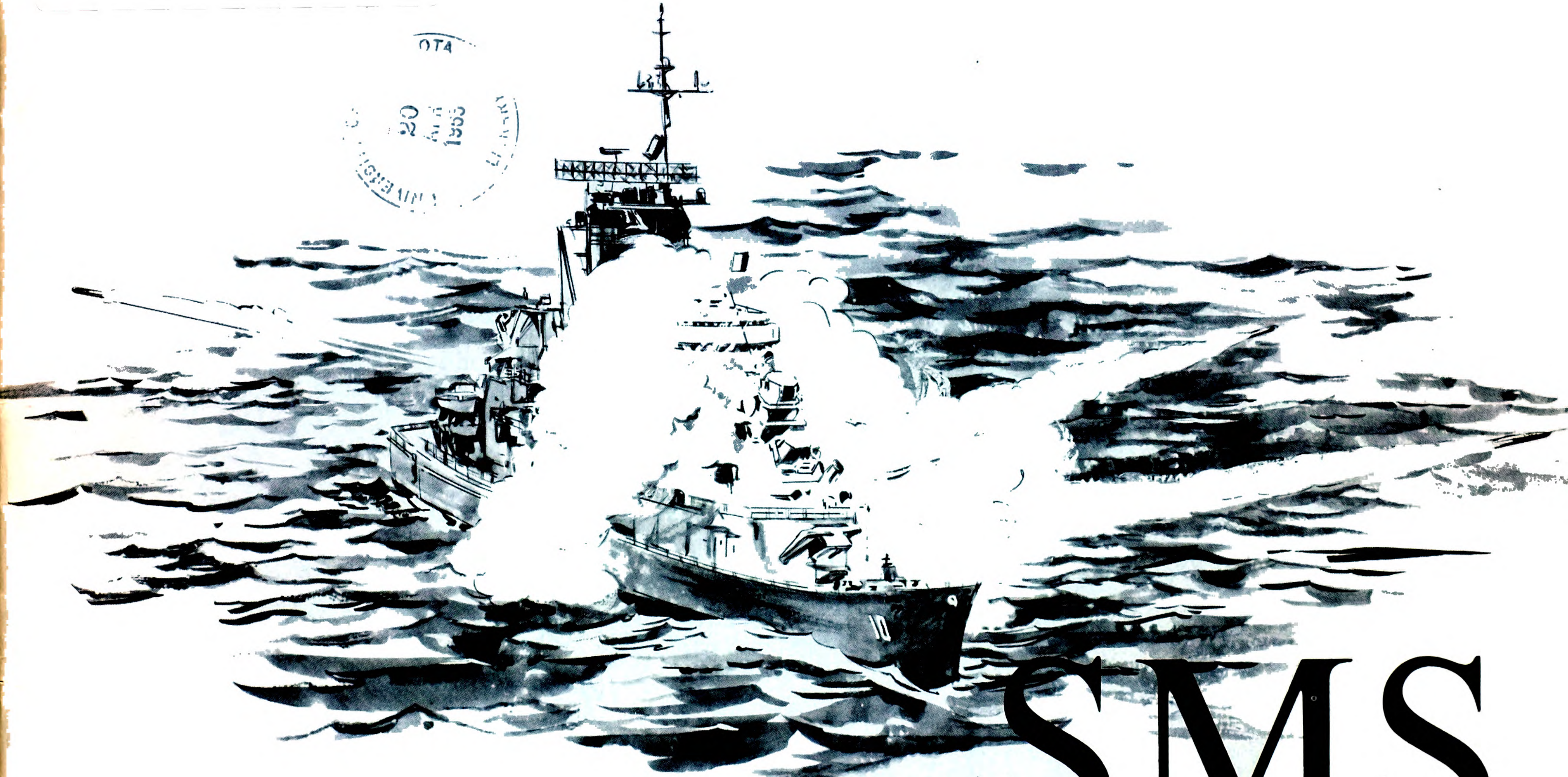

SMS

NAVY SURFACE MISSILE SYSTEMS

FOREWORD

The United States Navy today has nearly one hundred ships armed with surface-to-air missiles. These missile ships have assumed their places in the fleets that are deployed to implement United States policy around the world. Missiles, as anti-air weapons, have allowed the Navy to keep pace with other advances in weaponry that potential enemies have developed since World War II. Missile ships team with modern naval aircraft to form anti-air warfare forces that can operate in any ocean area required for accomplishment of assigned missions. Progress, however, must continue in step with the technical revolution in which we live. The United States Navy is, and will remain, engaged in a vigorous effort to maintain this weapon superiority in the most efficient and effective manner possible.

Eli T. Reich

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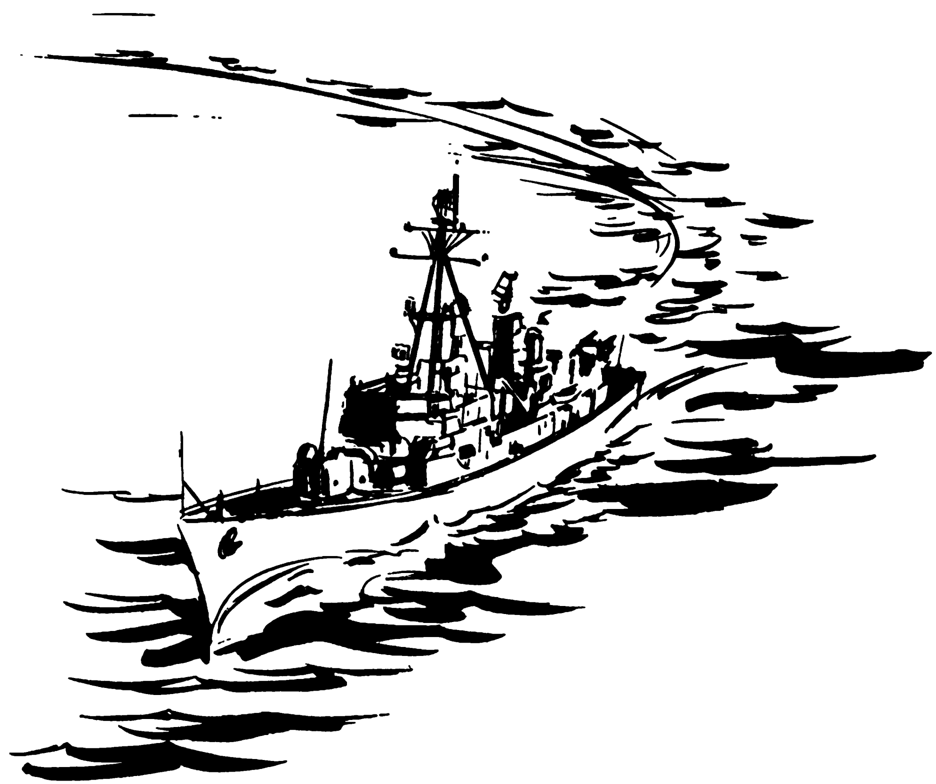
Director, Surface Missile Systems Project
Department of the Navy



REQUIREMENTS . . .

As far back as World War II, the Navy realized that the increased speeds being attained by the new aircraft required increased range, accuracy, and lethality for anti-aircraft weapons. The most careful firing of a ballistically aimed gun shell was totally inadequate at the ranges needed to provide fleet protection from the high speed jet planes. What was needed was a weapon with a speed greater than any planned aircraft, the accuracy of a manned interceptor, and a range longer than any existing gun system. Thus did guided missiles enter the Navy's sphere of interest. There were, however, many challenging problems to be solved. Guided missiles were in their infancy. They would have to be launched and guided from a moving ship. The range of radar had to be greatly increased. New methods had to be devised for accurate tracking of both the missile and the target. New high speed computers had to be used to provide speedy solutions to stabilization, aiming, and intercept problems. In short, the entire state-of-the-art would have to be greatly advanced to satisfy the Navy's needs. Intensive study was initiated with a propulsion system the primary consideration. Theoretically, a ramjet engine seemed to hold the most promise; its main advantages were simplicity (no moving parts), efficiency at high speeds, and a relatively high altitude capability. The main disadvantage was that at that time the

ramjet was only a theory and one had never been designed with enough thrust to overcome aerodynamic drag. But new propellants developed during the war were thought capable of solving this problem. Other disadvantages of the ramjet are its inability to develop static thrust (the engine must move at high speeds to operate efficiently and therefore requires an auxiliary booster) and, since it is an air breathing device, its inability to function above the atmosphere.

The ramjet uses reaction-type propulsion. Fuel and incoming air are burned in a fixed volume, producing a high pressure gas that is then forced out a small opening opposite the air intake. This gas, escaping at high velocity, pushes the engine in a forward direction. An example of a ramjet is shown in figure 1. The ramjet, moving to the left at high speed, forces air into the diffuser section. The diffuser is designed to change the high speed air of relatively low pressure to low speed air of high pressure. Fuel is forced in and mixed with the high pressure air. The spark plug initiates combustion, which is sustained from then on by the high temperatures existing in the combustion chamber. The combustion gases exert a force in all directions. The pressure barrier from the diffuser section prevents the gases from escaping out the front, but the gases can escape from the rear opening through the exhaust nozzle. The result is an unbalanced force in the forward direction that creates forward acceleration. The faster the ramjet moves forward, the higher the pressure of the intake air becomes and the higher the velocity of the exhaust gases. In practice the speed is limited only by the materials used to construct the ramjet and their ability to withstand heat generated by air friction.

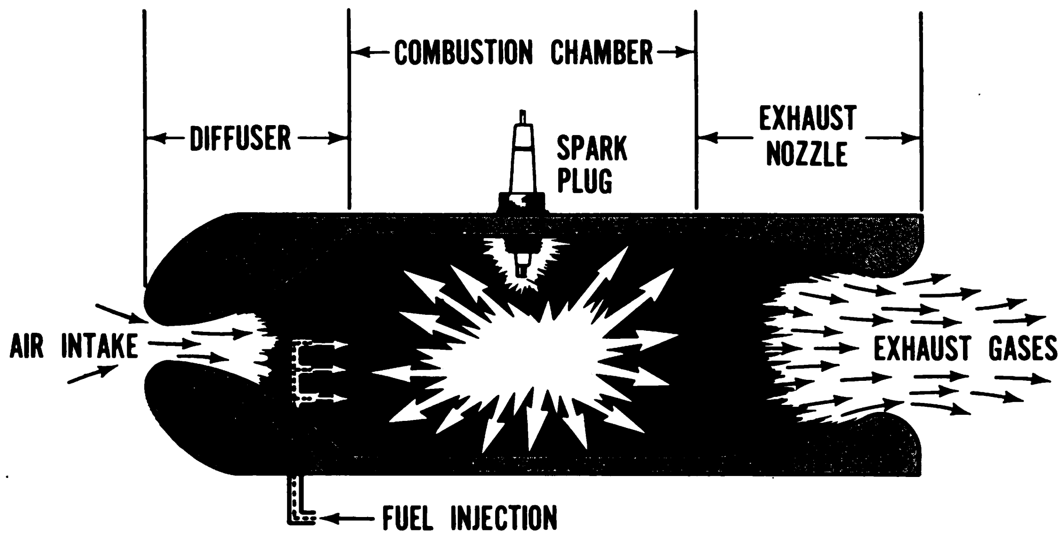


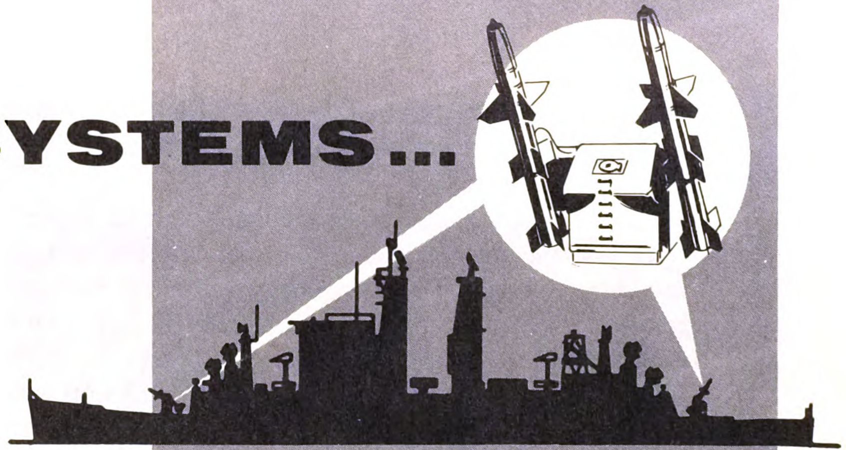
Figure 1.

GUIDED MISSILE SYSTEMS...

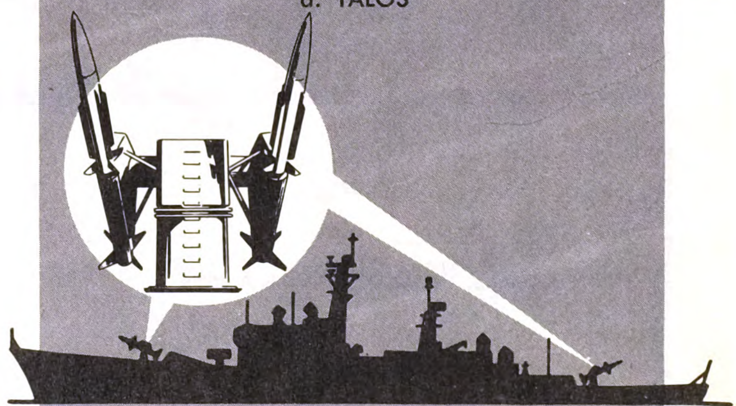
The Navy started work on an operational ramjet that was given the code name BUMBLEBEE. In June 1945, the first ramjet, constructed from a 6-inch exhaust pipe of a Thunderbolt plane, was successfully flight tested at Island Beach, New Jersey, attaining a velocity of 1,200 miles per hour. This first ramjet, dubbed the "flying stovepipe," was developed into the Navy's first surface-to-air guided missile. Today, this missile has grown to a diameter of 30 inches and a length of 30 feet. Utilizing a high-powered, solid-fuel rocket booster, it is known as TALOS (figure 2a).

For puposes of economy, a solid-fuel rocket was used in place of a ramjet in the early experimental TALOS system. In a solid-fuel rocket engine, the oxidating agent required for combustion (air in the case of the ramjet) is incorporated in the fuel. However, the reaction principle of the two engines is the same and therefore the rocket, with solid fuel, was used for testing. One disadvantage of the solid-fuel rocket is the limited range caused by the relatively rapid rate of fuel consumption. In 1949, this test vehicle was recognized as having possibilities as a tactically useful short range anti-aircraft missile of relatively simple design and was named TERRIER (figure 2b).

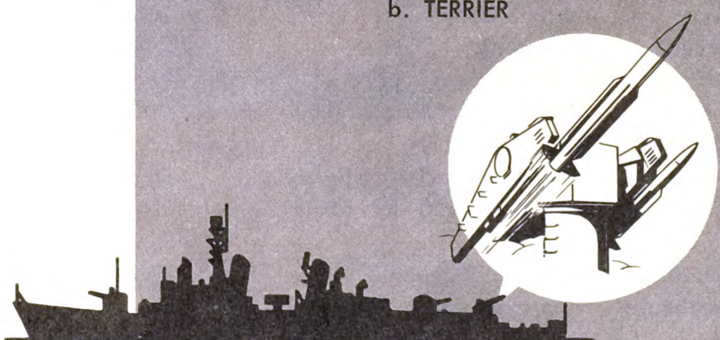
As work progressed on TERRIER, an idea of a missile for the smaller ships was conceived. Both TERRIER and TALOS, with their solid-fuel boosters, were too long for destroyer class ships. A method was devised to incorporate the solid-fuel booster and the rocket engine into one unit capable of installation aboard destroyers. This advance was called TARTAR (figure 2c).



a. TALOS



b. TERRIER



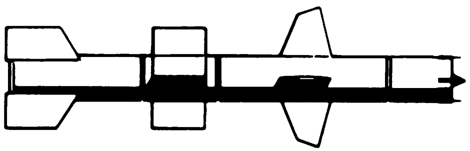
c. TARTAR

Figure 2.

These three missiles (TALOS, TERRIER, and TARTAR) today are known as the 3T's. The general characteristics are given below.

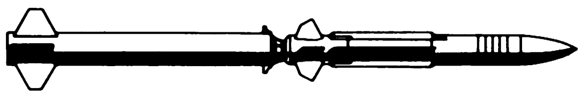
There is much more to a shipboard guided missile system than just the missile itself. The main functions of a system are shown in figure 3. The first requirement for efficient operation of any weapon system is surveillance. The most modern system is useless if targets cannot be located. The primary method used is search radars, with optical methods used as backup for the shorter range TERRIER and TARTAR missiles. After targets are detected by the search radars, an evaluation is performed to determine if they are friendly or hostile. If they are hostile, do they represent a threat to the fleet? They may pass the fleet and never come close enough to be considered a threat. If they are determined hostile and threatening, what method of defense will be used? Will interceptors or guns be used or will a guided missile provide the best protection? When a decision is reached to fire a missile, the launcher is loaded with the type of missile required and a fire control system is assigned to the target. A fire control system is the equipment used to guide the missile into the target path at an intercept area. The fire control system has a tracking radar that locks on the target and a fire control computer that takes

3T'S



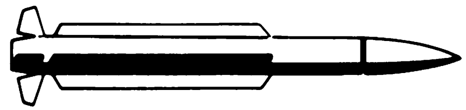
TALOS

Type:	Surface-to-air
Speed:	Supersonic
Range:	Over 65 miles
Length:	About 30 feet
Diameter:	About 30 inches
Power system:	Solid-fuel rocket booster plus 40,000 hp ramjet engine
Guidance:	Programed beamriding
Warhead:	High explosive or nuclear



TERRIER

Type:	Surface-to-air
Speed:	Supersonic
Range:	Over 20 miles
Length:	13 feet; 26 feet with booster
Diameter:	About 12 inches
Power system:	Solid-fuel rocket motor
Guidance:	Line-of-sight beamriding and semiactive (homing)
Warhead:	High explosive or nuclear



TARTAR

Type:	Surface-to-air
Speed:	Supersonic
Range:	Over 10 miles
Length:	About 15 feet
Diameter:	About 12 inches
Power system:	Dual thrust solid-fuel rocket motor
Guidance:	Semiactive (homing)
Warhead:	High explosive

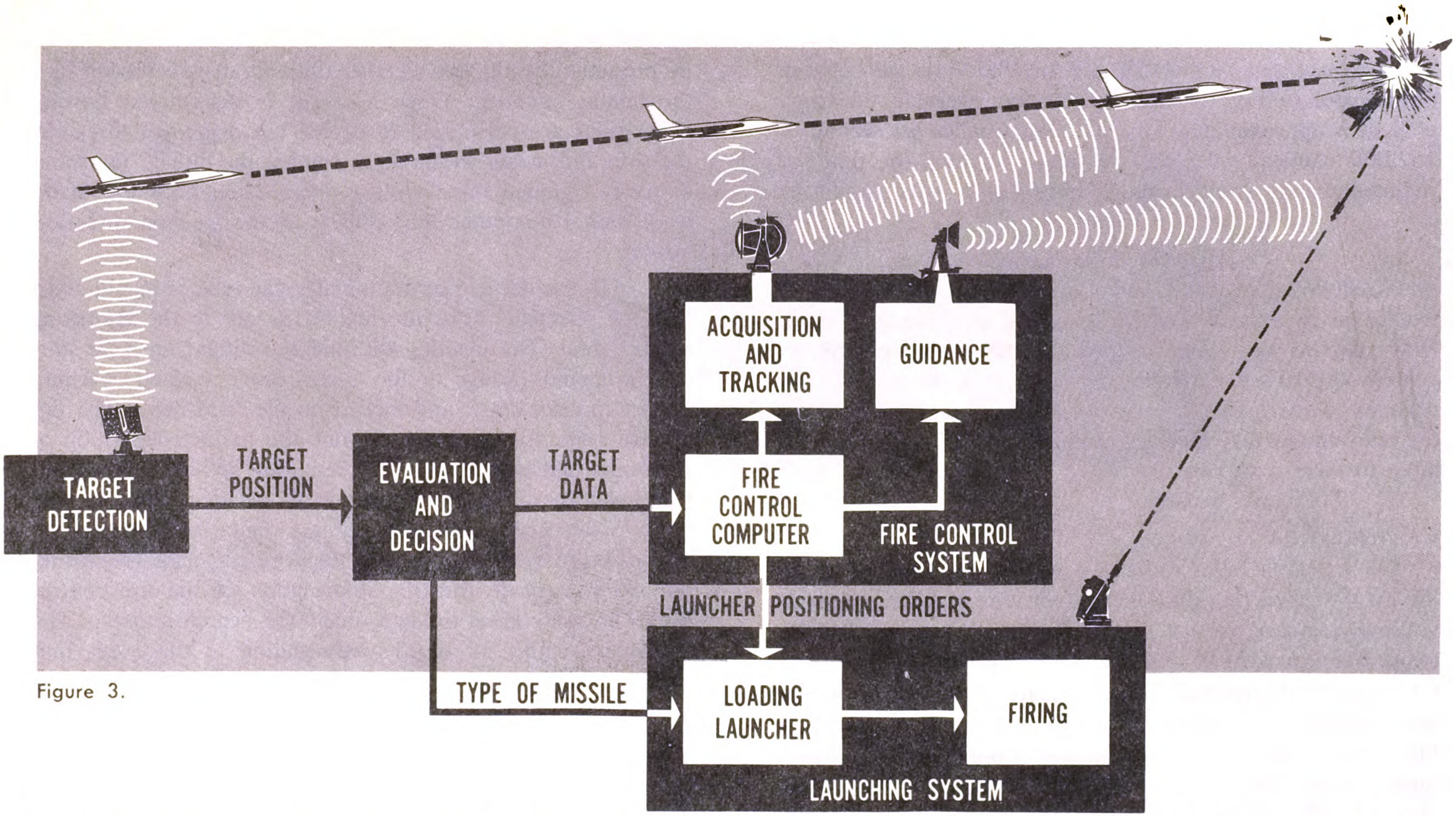


Figure 3.

the tracking information from the tracking radar, predicts a target intercept point, and sends orders to the launcher for proper aiming. The fire control computer also monitors such factors as speed and altitude of the target, wind velocity, motion and speed of the ship, and any other quantities that affect the fire control problem. The missile is then fired and guided to the target. When the missile reaches the area of the target, warhead detonation takes place, destroying the target.

Target detection can be of many forms. Sound, light, and heat can be used as detection devices. Today's modern Navy uses radar as the principal form of detection. The word "radar" comes from RAdio Detection And Ranging. A beam of electromagnetic energy is transmitted into space and, when this energy strikes an object, a portion of it is reflected back and picked up by a receiver. Since radio waves travel at approximately the speed of light, the distance from the radar

to the object can be calculated if the time interval between transmission and reception is known. For example, the speed of light is approximately 186,000 statute miles per second or 162,000 nautical miles per second. Therefore, the time for radiated energy from a radar to travel 1 mile would be

$$\frac{1 \text{ mile}}{162{,}000 \text{ miles/second}}$$

or 0.0000062 second. A radar mile, that is go and return, would be twice 0.0000062 second or 0.0000124 second. Now suppose we radiate energy at a target and receive an echo 0.000310 second later; how far away is the target? The distance to the target in miles equals the total time between the transmitted and received energy divided by the time it takes to travel one mile or

$$\frac{0.000310 \text{ second}}{0.0000124 \text{ second/mile}} = 25 \text{ nautical miles.}$$

A search radar radiates a wide angle beam to cover the greatest area possible. In addition, the radiating antenna is usually rotating so that, if the angular direction of the antenna when an echo is received is known, the bearing of the target can be determined. Therefore, any target that enters the area scanned by the radar beam is detected and appears as a blip on a cathode-ray tube. The next requirement is to determine whether the target is friendly or hostile. If the range is short enough, visual identification may be obtained, or if the range is long, visual identification may be made from another ship or an aircraft that is closer to the detected target. Another method of identification is IFF (identification friend or foe). IFF transmits a coded signal to the aircraft. The friendly aircraft, upon receiving the coded signal, transmits a reply back to the IFF equipment, identifying itself. Other considerations in identification are whether we are at war or in enemy waters (unidentified aircraft would more likely be presumed hostile) or whether the aircraft is behaving in a threatening manner. Once a target is determined hostile, evaluations are performed to decide the degree of threat to the ship and means available to combat the threat. On some of today's guided missile ships, these evaluations are made by a digital computer that is part of the weapon direction system.

If it is decided to fire missiles, the type of missile must then be selected. This information is sent to the launching system area. The missiles are quickly brought up from storage, prepared (wings or fins assembled if needed, warmup power applied, etc.), and loaded on the launchers. The fire control system is given the present and predicted position of the target and any waiting time required. When the fire control radar locks on the target, target position data are sent back to the weapon direction system digital computer. This allows the computer to continue updating target position using the more accurate tracking information of the fire control radar in preference to data from the search radars. The computer retains all of this information in the event that another fire control system is assigned to the target or a second salvo is required.

A more advanced system, the naval tactical data system (NTDS), is now being installed aboard some ships. This is a fleet-wide capability concept that is used in addition to the individual ship capability. With NTDS, any ship can obtain information about any target detected from any ship or plane in the area. It also creates a central authority for control of all fleet defenses. For instance, the flagship can control all interceptors, missiles, and other ships and can readily obtain all information from any of these sources. On a ship with NTDS, designation to a fire control system can be from the NTDS digital computer.

FIRE CONTROL . . .

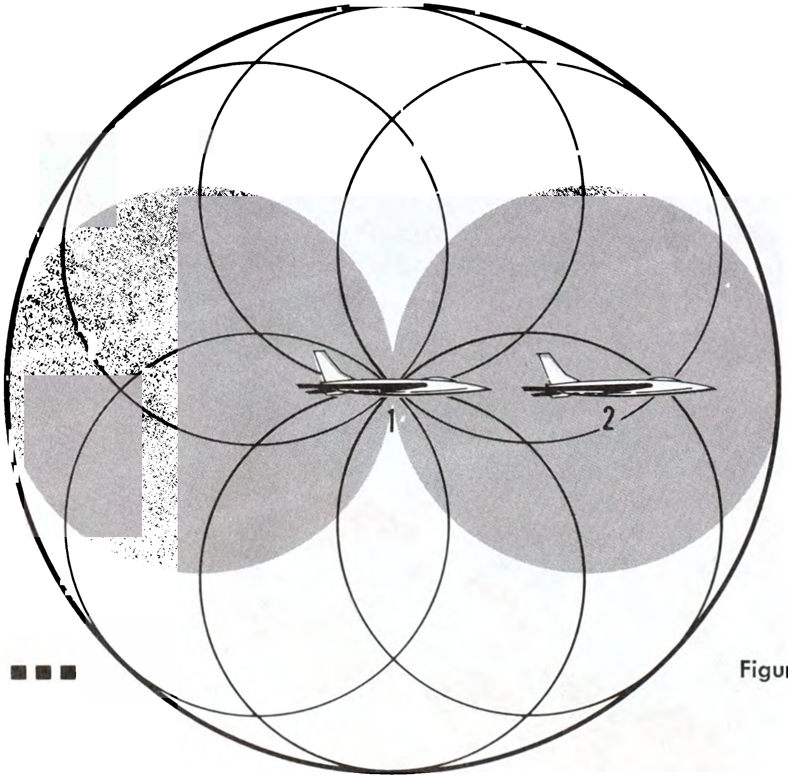


Figure 4.

Once a fire control system is assigned to a target, the designated data containing target position information are sent from the search radar to the fire control radar through the fire control computer. The fire control computer resolves the data into a form usable by the fire control radar. The radar then rotates its antenna to aim at the point in space where the target is supposed to be and radiates an acquisition beam, which is several degrees wide, and searches (scans) about the designated area. If the target is not located because of slight inaccuracies of target data that are preventing exact position location, the fire control radar performs a broader search pattern until the target is acquired. Radars can use either a mechanical or an electronic scan process. Mechanical scan relies on physical movement of the antenna, while electronic scan maintains a stationary antenna and the beam itself continually changes direction to provide a scan process. Once the target is acquired, tracking commences with a narrow (less than 2 degrees) tracking beam. The fire control radars are automatic trackers; that is, no matter how much the target speed or direction changes, the radar automatically compensates. One method of automatic tracking is nutating the tracking beam; that is scanning the beam in circles as shown in figure 4. With the target at 1, the strength of the radar return for each position of the nutating

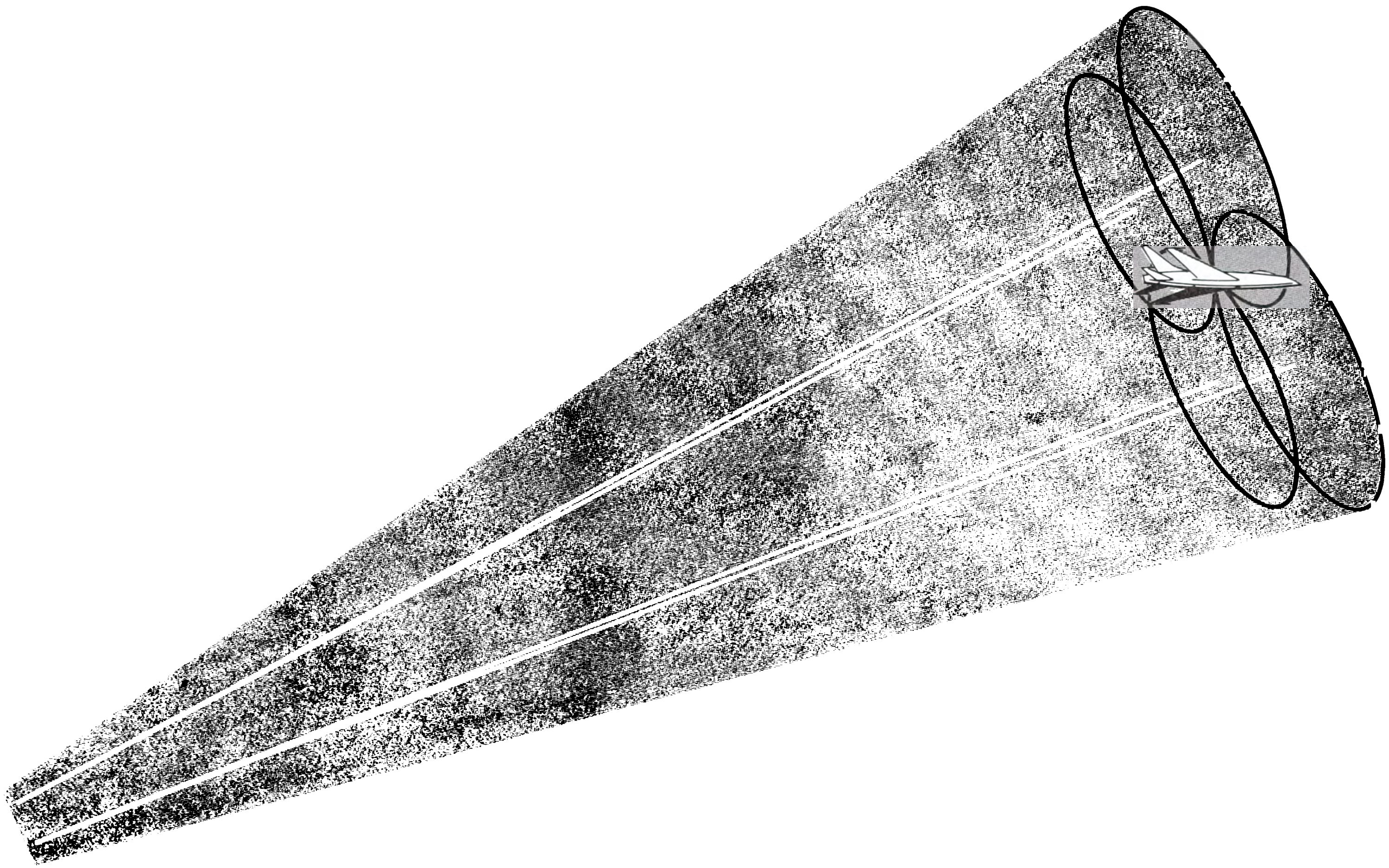


Figure 5.

beam is the same. Should the target move to position 2, the return from the beam when it is on the right side is much stronger than the return when it is on the left side. The radar, sensing this difference, will move to the right until the target is again centered. In this manner the target is automatically tracked. Radar Set AN/SPG–51, used with the TARTAR fire control system, uses such a method. Another method of automatic tracking is simultaneous lobing (figure 5). In this method a beam is radiating from four horns placed together to form a square. A separate lobe emanates from each horn forming a pattern about the target. When the target moves from the center of this pattern, the return received by each horn is different. By comparing the returns received by the four horns, the direction of target offset from the center of

the pattern is sensed and the beam is realigned to again center the target. Radar Set AN/SPG–49, used with TALOS, and Radar Set AN/SPG–55, used with TERRIER, both track using methods similar to this. The fire control radars presently used with 3T missiles and some of their characteristics are:

TALOS—Radar Set AN/SPG–49. A long-range, automatic-tracking, C-band radar with a transmitter for search, acquisition, and tracking.

TALOS—Radar Set AN/SPW–2. A C-band guidance radar used to capture and guide TALOS missiles to the target.

TARTAR—Radar Set AN/SPG–51. A medium-range, C-band, automatic-tracking radar with an X-band illuminator.

TERRIER—Radar Set AN/SPG–55. A medium-range C-band automatic-tracking radar with an X-band illuminator for homing missiles.

The fire control computer is used to solve the fire control problem; that is, calculating the predicted intercept point, determining the optimum launching angle and direction, programing the missile flight to the predicted intercept point, and calculating any other required information such as stabilization problems. The fire control computer keeps track of the target by continuous monitoring of the tracking radar. Similar monitoring of the guidance radar (used for guiding the missile) provides data on the missile while in flight. Inputs from the ship gyrocompass and stable elements permit corrections to be made to compensate for ship direction and motion. A typical prefiring problem for the computer is to predict the target intercept point. From the accurate tracking information of the fire control radar, the future target flight path is determined. Since there can be only one intercept point for any particular time, a time T_t must be determined (figure 6). This time must include the waiting time until firing T_w plus the time of missile flight T_m. Since the elapsed time between now and intercept must be the same for both missile and target, the present speed of the target multiplied by this elapsed time will give the distance the target can go in time T_t. This distance added to present target position and the

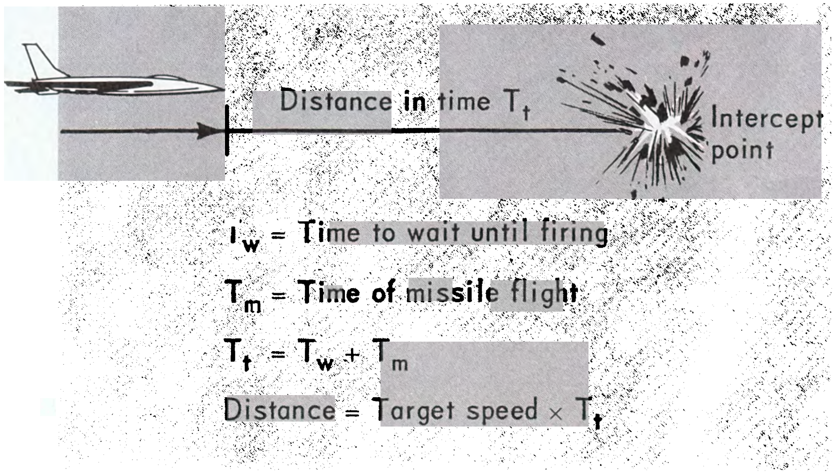


Figure 6.

direction the target is proceeding will produce the predicted intercept point for that period of time.

The fire control computer also determines the launcher positioning orders. In addition to missile and target values needed to aim the launcher, the effects of wind, ship motion, and gravity must also be compensated for and incorporated into the final launcher positioning orders. For homing missiles,

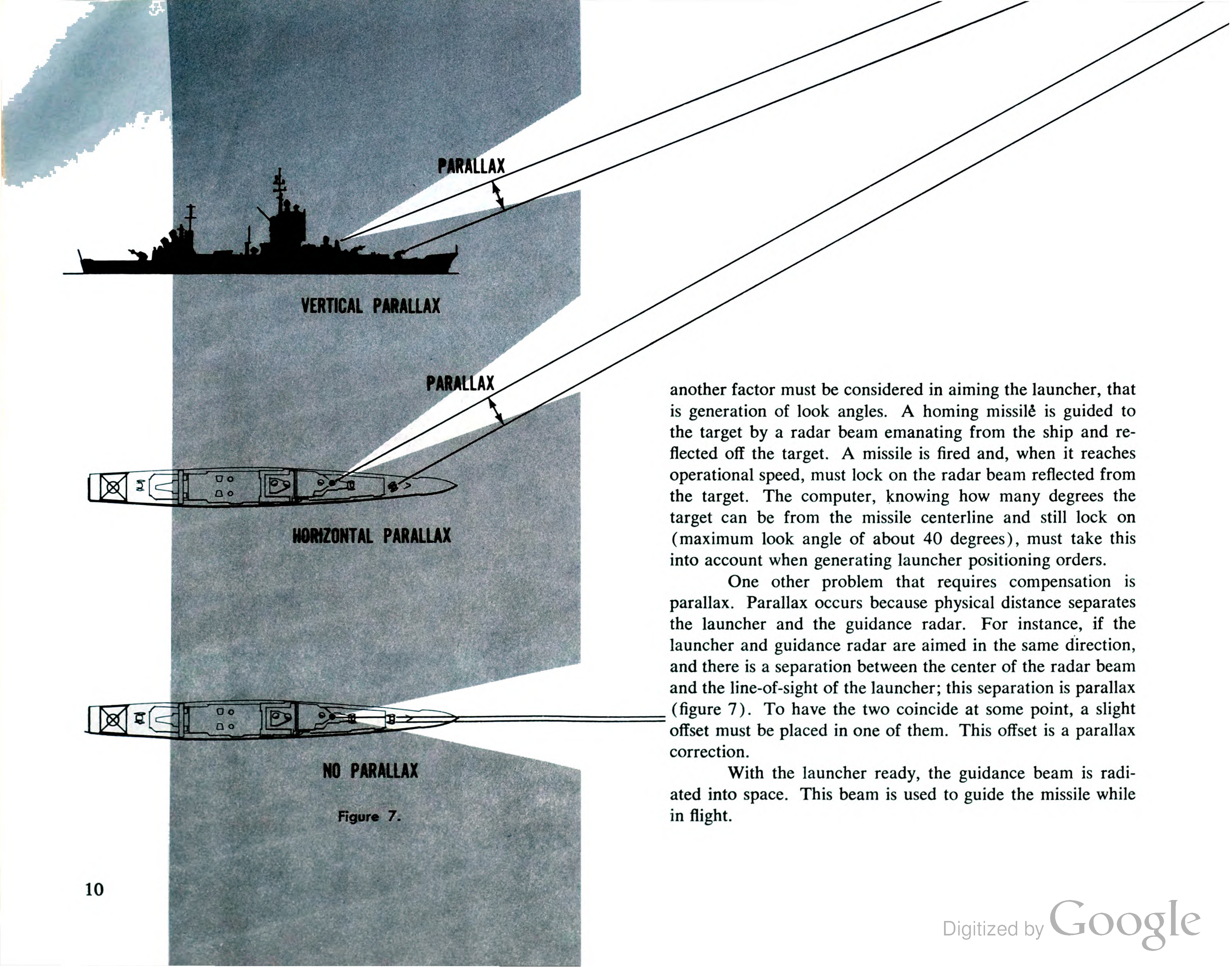


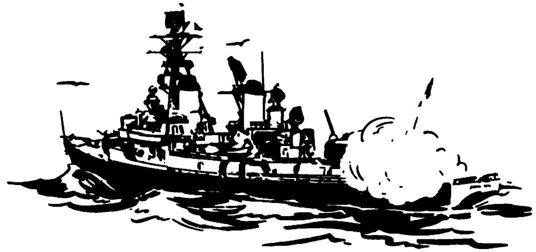
Figure 7.

another factor must be considered in aiming the launcher, that is generation of look angles. A homing missile is guided to the target by a radar beam emanating from the ship and reflected off the target. A missile is fired and, when it reaches operational speed, must lock on the radar beam reflected from the target. The computer, knowing how many degrees the target can be from the missile centerline and still lock on (maximum look angle of about 40 degrees), must take this into account when generating launcher positioning orders.

One other problem that requires compensation is parallax. Parallax occurs because physical distance separates the launcher and the guidance radar. For instance, if the launcher and guidance radar are aimed in the same direction, and there is a separation between the center of the radar beam and the line-of-sight of the launcher; this separation is parallax (figure 7). To have the two coincide at some point, a slight offset must be placed in one of them. This offset is a parallax correction.

With the launcher ready, the guidance beam is radiated into space. This beam is used to guide the missile while in flight.

GUIDANCE . . .



When everything is ready, an electrical charge is applied to the missile, ignition takes place, and the missile leaves the launcher. The initial thrust developed can be as high as 400,000 pounds but this is only required for a short period of flight. This first phase is called the boost phase and is used to get the missile to operational speed. The boost phase is unguided and the missile flies a ballistic type trajectory. For the TERRIER and TALOS missiles, the boost phase terminates when the booster separates. The TARTAR missile, which has no separate booster, uses a dual-thrust rocket motor. Two types of propellant are used in the one rocket engine: a fast-burning, high-thrust propellant is used for the boost phase; when this is consumed, a slower burning, longer-lasting propellant is used.

The second portion of missile flight is the midcourse phase and is a guided phase. There are numerous types of guidance but, for the midcourse phase, the 3T missiles are confined to two: beamriding and semiactive homing. Variations of beamriding guidance are used by TALOS and some TERRIER missiles. The missile is guided or rides in a radar beam that is radiated from the ship. Semiactive homing guidance is used with TARTAR and some TERRIER missiles. When semiactive homing guidance is used, the target is illuminated by a source external to both the target and missile. For TARTAR and the semiactive homing guided TERRIER's, this illumination is a radar beam from the ship that is reflected off the target. The missile receives this reflected energy and compares it with a reference beam received directly from the ship. The missile can then determine the direction and speed of the target.

The TALOS uses a two-radar programed beamriding principle. The tracking radar tracks the target and is independent of the guidance radar, which guides the missile. The missile is fired in a direction so that after booster separation it will fly into the guidance beam and be captured by it.

After capture, there are three programed trajectories possible for TALOS. Essentially, the computer causes the guidance beam and tracking beam to come together as the range of the missile becomes equal to the range of the target. Thus, the two beams should coincide when the ranges are equal. An A trajectory, which is used for short and medium range firings, is a curved flight path when viewed from the side (figure 8a). When viewed from above (figure 8b) for short ranges (below 30,000 yards) a line-of-sight path is used. For medium ranges a lead angle is provided and the programed beam brings the missile to the intercept point. B trajectory is used for short and medium range firings when accurate ranging information is not available. The separation between the tracking and guidance beams is closed rapidly and the missile flies line-of-sight to the target (figure 9). The B trajectory is used when: (1) accurate missile range is not available, and the missile is flying an A trajectory (the computer automatically switches to a B trajectory); (2) accurate target range is not available (a B trajectory program would provide the best chance of intercept). For an L trajectory, which is used for long range targets, the missile is fired and climbs rapidly to

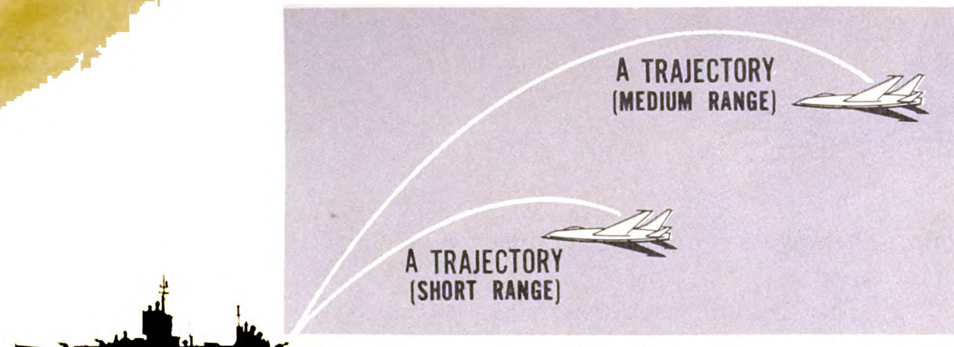


Figure 8 a.

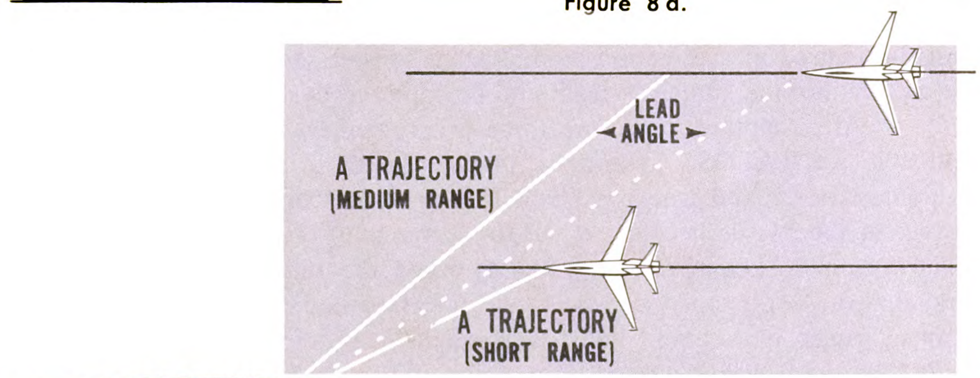


Figure 8 b.

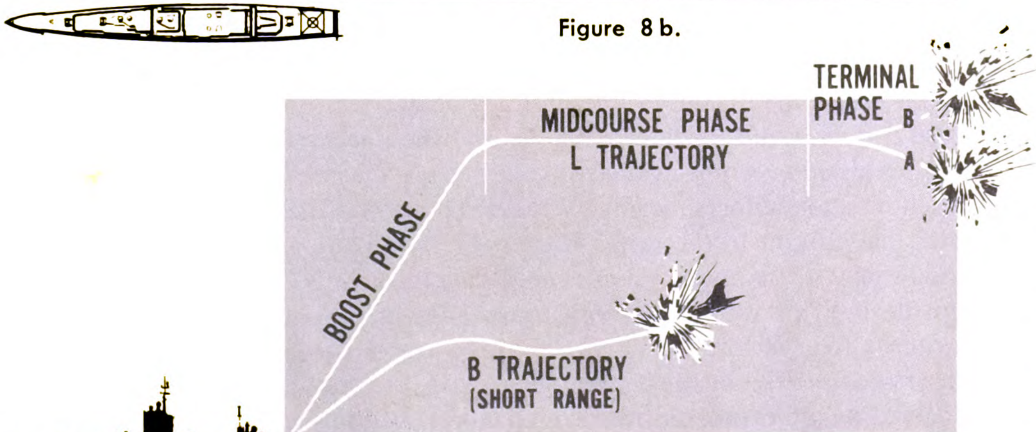


Figure 9.

an altitude that provides maximum efficiency for the ramjet engine (figure 9). The missile cruises at this optimum altitude, thereby obtaining maximum distance from available fuel. Closing of beam separation does not occur until the terminal phase of flight. The terminal phase of an L trajectory can use either an A or B trajectory depending upon the altitude of the target. If the missile is higher than the target, it comes down on the target in an A trajectory. If the missile altitude is below target altitude, the line-of-sight B trajectory is used.

The TERRIER missiles are of two types. One type is line-of-sight beamriding and the other is a homing-type missile. The TERRIER beamriding missile is a one radar beamrider. The missile is captured and centered in the guidance beam, and this beam is always in line with the beam tracking the target (figure 10). A straight line from the radar to the target will always pass through the missile. The missile therefore turns at a rate proportional to the tracking rate of the radar (figure 11). The TERRIER homing missile, which uses semiactive guidance, requires two radiating beams for guidance. One beam tracks the target; a second beam is reflected off the target into the front end of the missile. A portion of this second beam is also used as a wide angle reference (figure 12). After booster separation the missile locks on and homes in on the beam reflected from the target.

The TARTAR missile is a homing missile. After boost phase, it operates in the same manner as the TERRIER homing missile.

How does the missile remain in the guidance beam? Since the beam cannot compensate for missile variance, the missile is responsible for staying in the center of the guidance beam. This is accomplished by nutating the guidance beam (figure 13). With the missile at the center, the strength of the beam received by the missile is the same for every position of the beam. Should the missile move off center, the strength

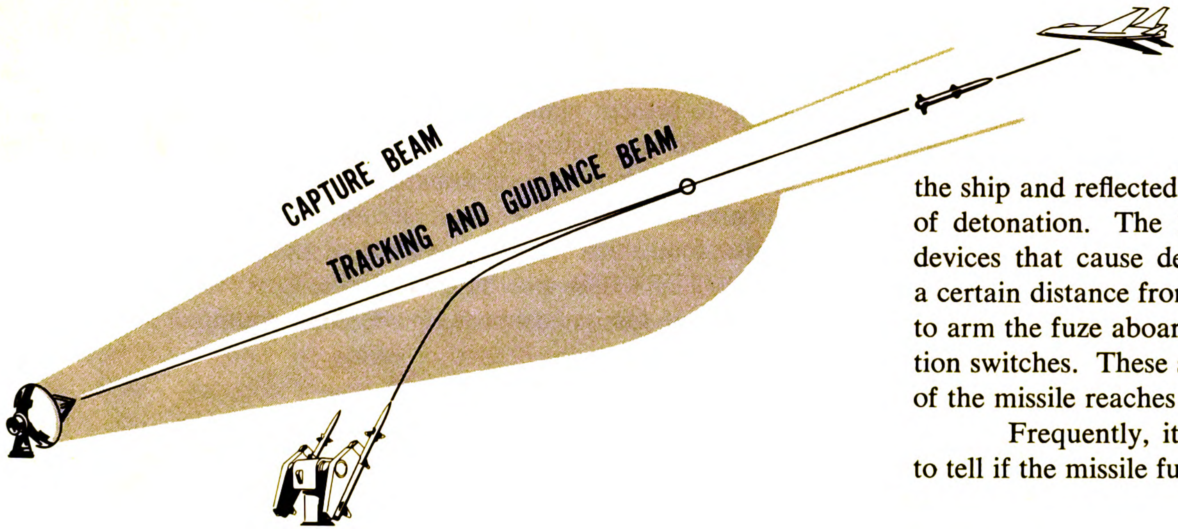


Figure 10.

of the signal received will vary as the beam is nutated; thus the missile can tell how far it is from the beam center. However, the missile still does not know in which direction to go. A direction reference must be established. The pulse rate of the nutating guidance beam is varied as the beam is nutated, establishing a sense of direction. For example, if the highest pulse rate occurs at the reference, the amount of decrease in pulse rate will determine the direction the missile is from the reference. With the distance and direction from beam center known, the missile adjusts its control surfaces (tails) to return to beam center.

The third phase of missile flight is the terminal phase. This occurs in the last few seconds of flight in the area where detonation takes place. The TERRIER and TARTAR missiles maintain the midcourse guidance, beamriding or semiactive (homing), through the terminal phase. The TALOS missile, however, changes from midcourse programed beamriding to semiactive homing in the terminal phase. The TALOS missile homes in on a radar beam originating from the ship and reflected off the target. There are several methods of detonation. The 3T's all use proximity fuzes, which are devices that cause detonation whenever the missile is within a certain distance from the target. Since it would be dangerous to arm the fuze aboard the ship, the fuze is armed by acceleration switches. These switches close only when the acceleration of the missile reaches a predetermined value.

Frequently, it is necessary to monitor a missile flight to tell if the missile functions properly, or, if it aborts in flight,

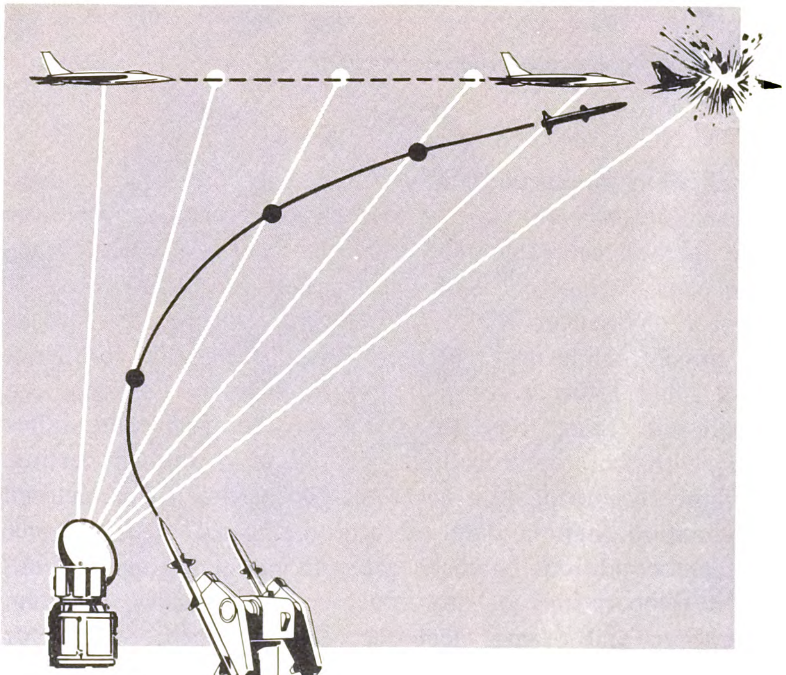


Figure 11.

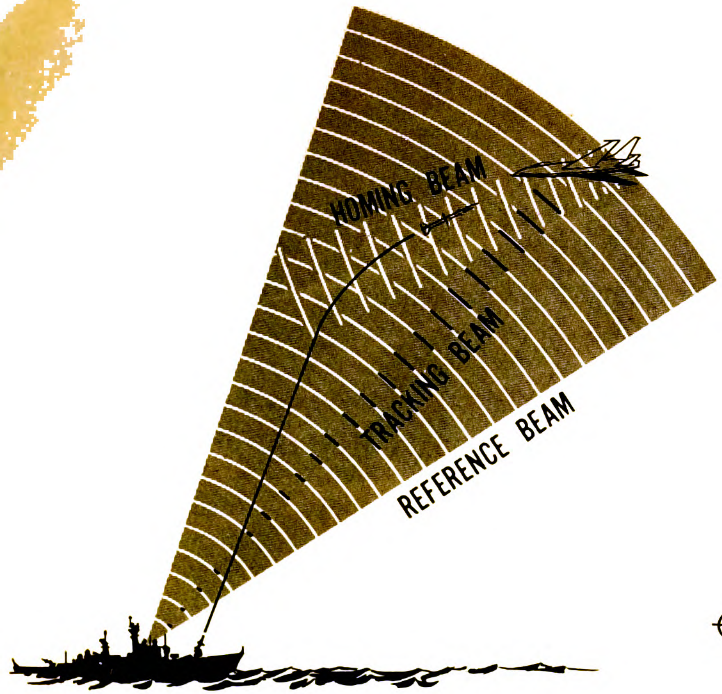


Figure 12.

to tell what caused the malfunction. A missile is not recoverable and there is no pilot to send back pertinent information. The method used to obtain this information is telemetering. The word "telemeter" is of Greek origin and means measurement at a distance. With a telemetering package on a missile, the missile, while in flight, sends back to the ship, by means of a small radio transmitter, information on the functions monitored. Since these functions may be performed differently with the missile in flight than when in preflight testing, in-flight monitoring is a necessity. Examples of telemetered information include data on attitude, speed, accelerations, ambient conditions (such as pressure, temperature, and humidity), operations of any moving parts, electrical system operation, and fuzing elements. The measuring device or sensor monitors the function and converts the measurement to an electrical signal that is then transmitted back to the ship.

The ultimate size of the Navy's guided missile fleet, according to present plans, will be nearly 100 ships. TARTAR systems are on destroyers, destroyer escorts, and a carrier. TERRIER systems are on frigates, light and heavy cruisers, and carriers. TALOS systems are on light cruisers. There are also four ships (cruisers) with dual missile systems: one TALOS/TERRIER and three TALOS/TARTAR. In addition, several foreign countries have ships equipped with the Navy's missiles.

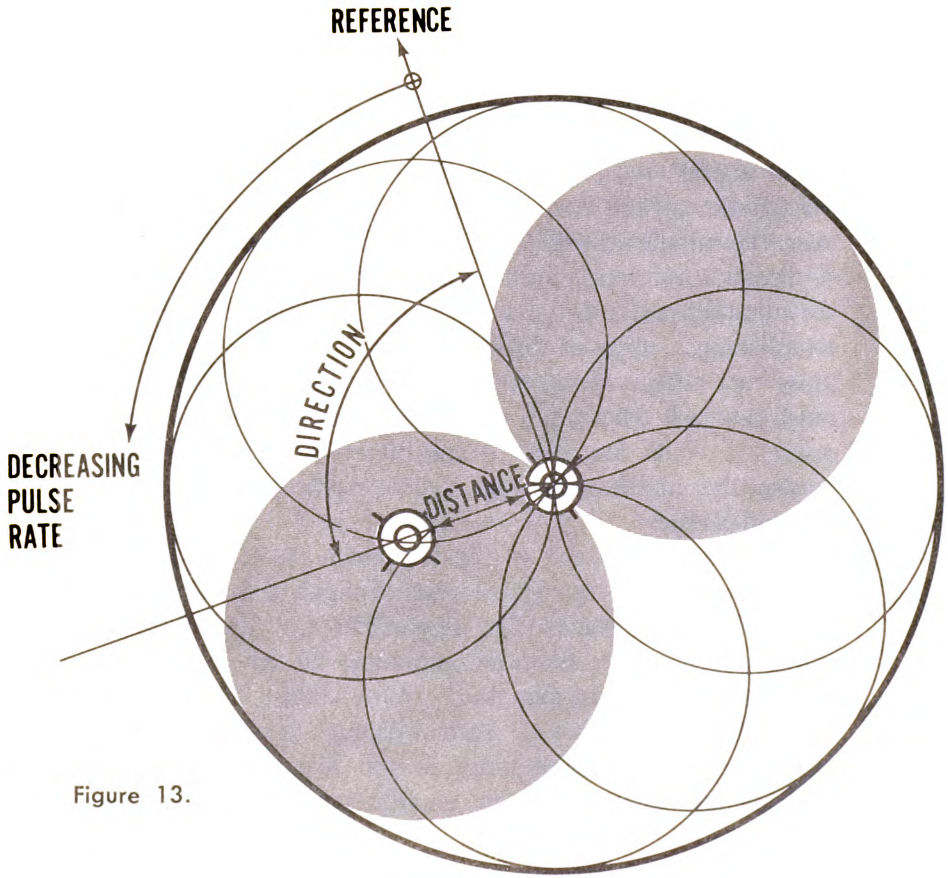


Figure 13.

TRAINING . . .

The manning requirements for a fleet this size are prodigious. First, the education and training involved to produce men of the high caliber required to operate and maintain the complex equipments of a guided missile weapon system are difficult to maintain. Second, the number of personnel needed to man the guided missile fleet is difficult to find. In today's Navy, a young high school graduate with some math and science courses and of sufficient intelligence, ambition, and initiative to become part of the missile team faces a unique opportunity. The Navy will guarantee schooling, the number of classroom hours equaling the hours required for a 4-year college program. Besides being trained on the most modern equipment available, these men obtain experience with the actual shipboard weapon systems. The Navy also sends qualified young men to regular colleges. In today's Navy, the missile man not only becomes an expert in radars, missiles, computers, and related fields, but he takes an active part in new developments and in helping to advance the state-of-the-art.

GLOSSARY

ACQUISITION. The transition phase between target designation and target tracking by a missile fire control radar set. (Refer to designation and track.)

ASSIGNMENT. Used interchangeably with designation.

ATTITUDE. General term of reference to a missile in-flight roll, pitch, and yaw angles relative to the earth.

BALLISTIC. General term applied to the flight path of an aimed but unguided missile, as during the boost phase.

BLIPS. Radar echoes that are displayed as points of light on a cathode-ray tube.

BOOSTER. Rocket motor used for propelling a guided missile to flight speed.

CATHODE-RAY TUBE. General term for a device that uses cathode rays (beamed electrons) to trace a picture or other information on a phosphor-coated screen, as in a television picture tube.

DESIGNATION. The act of assigning a missile fire control system to a target lying at a designated range, bearing, and elevation.

ILLUMINATE. The general term for directing a radar beam toward a target so that a radar receiver can locate the target by the radar reflections.

LINE-OF-SIGHT. In missile fire control theory, the geometric center of a radar beam tracking a target; the basic element, along with radar range and range rate, from which the solution to a fire control problem is derived.

LOCK-ON. In fire control radar terminology, the closing of relays that signal successful target acquisition and initiate target tracking.

SALVO. One or more missiles fired singly or simultaneously at a target.

SCAN. The systematic searching of a fire control radar beam in a small volume of space that supposedly contains a target; follows designation and precedes acquisition and lock-on.

SENSOR. General term for a device that is designed to respond to physical stimuli (as heat or cold, light, a particular motion) and transmit a resulting impulse for interpretation or measurement or for operating a control.

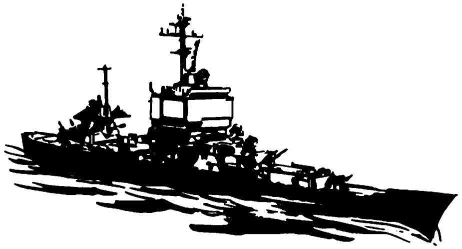
STABLE ELEMENT. A gyroscopic device that supplies the missile fire control computer with an indication of true vertical regardless of the pitch and roll motion of the ship.

STATE-OF-THE-ART. General term that refers to the level (state) of the design and production techniques (art) possessed by an industry at some period in history.

SUSTAINER. A rocket motor or ramjet engine that propels a missile at a steady (sustained) speed during the period of guided flight.

TRACK. In fire control radar terminology, the continuous and self-correcting pointing of a radar beam at a (usually moving) target.

WARMUP POWER. Electrical power applied to a missile prior to launching, the purpose of the power being to warm electronic components to the operating level.



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- Bendix Corporation
- General Dynamics
- General Electric Company
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